GUIDELINES FOR THE GEOTECHNICAL INVESTIGATION AND ANALYSIS OF EXISTING EARTH DAMS

DEPARTMENT FOR NATURAL RESOURCES AND ENVIRONMENTAL PROTECTION

COMMONWEALTH OF KENTUCKY
DEPARTMENT FOR NATURAL RESOURCES
AND ENVIRONMENTAL PROTECTION
BUREAU OF ENVIRONMENTAL PROTECTION
DIVISION OF WATER

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JUNE 1, 1980

DIVISION OF WATER

FRANKFORT, KENTUCKY 40601

PURPOSE

The purpose of this document is to outline the basic components of an adequate geotechnical investigation for dams and to provide a generalized set of guidelines for such an investigation. This booklet has been written pursuant to the provisions set forth in KRS 151.125(2).

An additional purpose of this document is to provide to dam owners a general outline of typical geotechnical investigations on earth dams. It has been the observation of this division that a general explanation and description of this type of investigation can be of benefit to dam owners by providing them with some background information on which to base their decisions. We further believe that engineers performing this type of work will benefit by having a better definition of the information we require in our analyses performed as part of construction permit application review and safety inspections.

The general application of this publication is limited to existing earthfill dams or other impounding structures constructed of earth or similar materials. Although some aspects may be applicable to any dam, care must be exercised in any extrapolation of this discussion.

REGULATORY REQUIREMENTS

Regulations which established minimum safety and design criteria for dams and associated structures were first promulgated in 1967. The regulation, 401 KAR 4:030, and Engineering Memorandum No. 5, which is a part of that regulation, applies to all dams and other potentially hazardous impounding structures. Any structure, including dams as defined in KRS 151.100, which might create a hazard to life or property is defined in Engineering Memorandum No. 5 as having either moderate or high hazard potential. These classifications are repeated as follows:.

1. **CLASS (B)-MODERATE HAZARD** This classification may be applied for structures located such that failure may cause significant damage to property and project operation, but loss of human life is not envisioned. Such structures will generally be located in predominantly rural agricultural areas where failures may damage isolated homes, main highways or major railroads, or cause interruption of use or service of relatively important public utilities.

2. **CLASS (C)-HIGH HAZARD** This classification must be applied for structures located such that failure may cause loss of life, or serious damage to homes, industrial or commercial buildings, important public utilities, main highways or major railroads. This classification must be used if failure would cause probable loss of human life.

The Division of Water is required by KRS 151.295 to perform safety inspections of all dams in Kentucky. These inspections are primarily visual but include such things as the review of plans and specifications, design data, and the performance of flood routings to determine the approximate rainfall which will overtop the dam. When inspections reveal conditions or deficiencies which may or do endanger life or property, KRS 151.297(1) requires that the owner be ordered to render the dam safe.

The process of rendering the dam safe requires that the owner's engineer evaluate the dam, determine the appropriate hazard classification, and design repair or reconstructive measures to bring the dam into compliance with the minimum safety criteria of the Commonwealth. If the dam is to remain in service, safety deficiencies must be corrected. Any structure which is to be modified or reconstructed must be made to conform to the criteria which have been established by the regulations.

Section 10 of regulation 401 KAR 4:030 requires that all structures, other than low hazard structures, have a complete subsurface investigation and soils analysis submitted as an integral part of the drawings. The purpose of the investigation and analysis is to determine the stability of the structure and to assure that any repair or reconstruction results in the establishment of appropriate minimum factors of safety against slope failure.

BACKGROUND

Depending upon the source of reference, structural and seepage related deficiencies may account for 50 to 70 percent of dam failures. The evaluation of the geotechnical information is an essential component in the determination of structural stability. An adequate assessment of the safety of a dam must include a detailed geotechnical investigation and analysis. These determinations are generally made by civil engineers who are experienced in geotechnical engineering.

When applied to dams, geotechnical investigations should deal with such areas as exploration, instrumentation, seepage evaluation, soil sampling, soil testing and the performance of stability analyses.

For purposes of presentation, geotechnical investigations will be considered in three general phases:

1. Exploration

2. Testing

3. Analysis

It must be understood that these phases are highly interdependent. For example, a less than adequate subsurface exploration can greatly limit the useful information which would be obtained from the later phases of testing and analysis. There is no substitute for qualified, experienced personnel in the performance of each phase of this work.

Site conditions will have a great impact on the quantity of work that is necessary. Aspects such as the dam's height, length, function and importance may require that additional considerations be given to many aspects set forth in this document. Therefore, these guidelines can not, nor are they intended to be all-encompassing. However, these guidelines can be used by the owner as an indication of the minimum investigation which will be acceptable. It is felt that the engineer can justify, to the owner, other work which he determines will be necessary.

EXPLORATION

The term exploration as used in this phase of the geotechnical investigation refers to the subsurface work performed at the dam site. It includes such items as soil and rock borings and field testing and evaluations. Explorations are normally confined to the embankment and foundation materials at the dam unless there are explicit reasons for exploration in separated areas. Conditions which may call for additional investigation may include such features as cavernous limestone foundations, landslide problems in the area, zones of faulting, and the investigation of potential borrow areas.

An area which should be examined in any exploration deals with available information. General geologic information is available from government agencies such as the United States Geological Survey (USGS) and the Kentucky Geological Survey (KYGS). Areal geologic maps based on the 7 1/2 minute topographic quadrangles are available for all of Kentucky and should always be reviewed as a part of any geotechnical investigation.

The exploration serves several functions which should include the specific items noted below:

1. Identification of soil horizons in the embankment and foundation, that is, soils with differing properties for engineering purposes.
2. Obtaining soil samples for subsequent laboratory testing.
3. Performance of field tests which can later be used to corroborate laboratory test results.
4. Determination of the level of the free water (phreatic) surface within the embankment.
5. Installation of instrumentation to monitor such things as slope movement and variations in the phreatic surface.

The number and location of borings which form the bulk of the exploration will vary, depending on the height and length of the dam, geologic conditions in the area and the complexity of the dam. The following list sets forth a minimum boring program which the division believes can establish a reasonable basis for subsequent analyses.

MINIMUM BORING LAYOUT

1. One (1) crest boring extending through the embankment and foundation materials to bedrock for each 250 feet of crest length, arranged such that one boring is located at or reasonably near the maximum section.

2. One (1) crest boring extending through the embankment and foundation materials to bedrock near each abutment; these borings should be located such that the phreatic line should be intercepted.

3. If access is reasonably attainable (side slopes not steeper than 3H to 1V or berms are present), one boring extending through the embankment and foundation materials to bedrock near each abutment near the midheight of the dam on the downstream slope of the dam; additional borings on the downstream slope should, if attainable, be taken at intervals not to exceed 250 feet.

4. One (1) boring opposite each boring advanced from the crest extending through the foundation material to bedrock along the toe of the dam.

NOTE: All borings should extend into the foundation material a minimum depth of one half the height of the embankment or to bedrock. Borings may be terminated in foundation soils when they penetrate a 'firm, impervious' stratum which will not settle, fail in shear or permit excessive seepage. This determination requires considerable judgment in certain cases and experience is very important.

NOTE: Generally, to better establish the rock line, soil horizons and phreatic surface, borings on the crest, slope and at the toe should be located on or reasonably near cross-sections through the dam.

Borings may be desirable or necessary at other locations. Conditions which may require additional borings include seepage areas on or near the abutments, seepage areas along the toe of the embankment, data from previous investigations which show a lack of homogeneity of the embankment materials, and evidence that the embankment is zoned into distinctive areas of different materials.

For new construction, borings are usually required at the location of appurtenant structures such as spillway structures and open channel spillways. However, existing embankments usually do not require the geotechnical investigation of appurtenant structures unless there is evidence of instability, damage or the need for major modifications.

All proposed borings should be approximately located in any engineering proposal submitted to this division. In the report on the actual investigation all borings must be accurately located on a boring plan and the elevation information noted on the boring log. The boring plan and logs should be plotted on scale drawings for ease of use. Examples of typical boring plans and logs are shown in Figures 1 and 2. These figures also provide an idea of typical layouts for borings on dams.

FIGURE 1

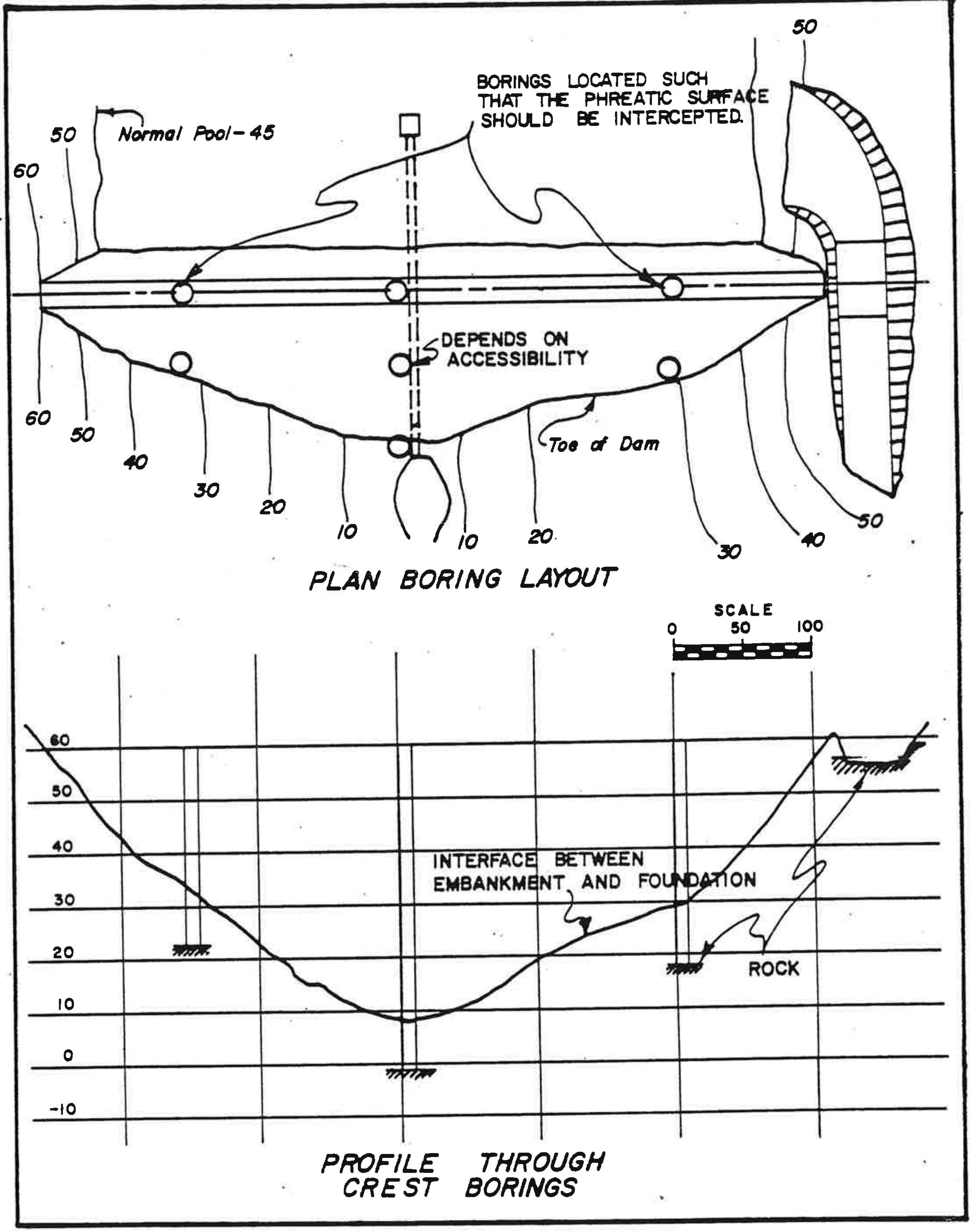
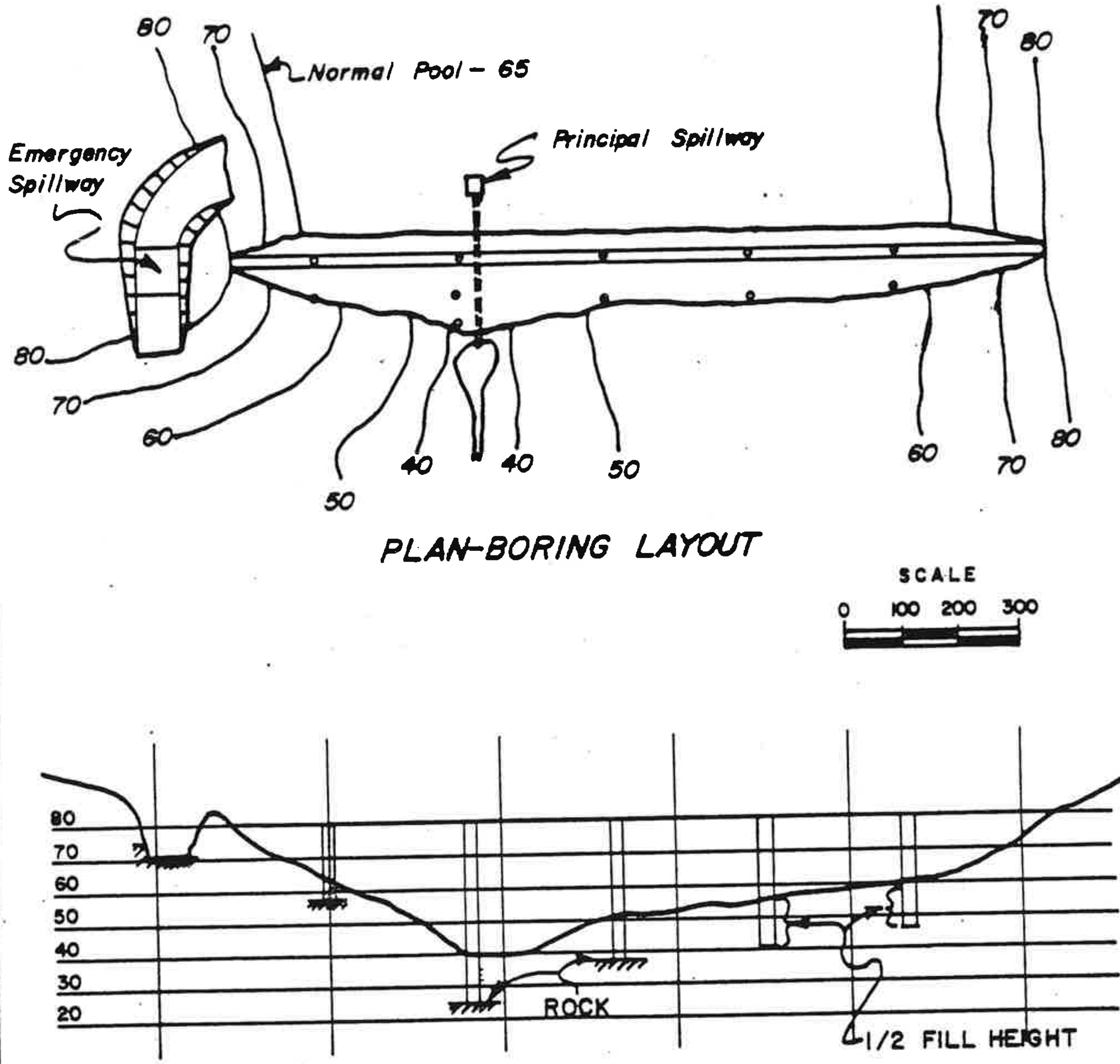

BORINGS LOCATED SUCH THAT THE PHREATIC SURFACE SHOULD BE INTERCEPTED.
Normal Pool-45
50
60
DEPENDS ON ACCESSIBILITY
Toe of Dam
60
50
40
30
20
10
10
20
30
40
50
PLAN BORING LAYOUT
SCALE
0
50
100
60
50
40
30
20
10
0
-10
INTERFACE BETWEEN EMBANKMENT AND FOUNDATION
ROCK
PROFILE THROUGH CREST BORINGS

FIGURE 2



PROFILE THROUGH CREST BORINGS

NOTE: SHOW OTHER BORINGS ON SEPARATE SHEETS OR OTHER APPROPRIATE MANNER.

The accurate location of subsurface zones and features can provide a reasonable basis for interpolation and extrapolation of boring information. The accurate location of embankment zones can have a significant impact on the reliability of a stability analysis. Identification and location of discontinuities, such as zoning interfaces, buried pipes, and planes formed by past additions, may be crucial to a stability analysis.

The accurate location of borings requires some level of site mapping. This mapping may be performed in conjunction with other investigations such as hydraulic or hydrologic studies and the preparation of remedial plans. Regardless of the basis for mapping, all borings must be accurately shown on scale drawings.

During the process of advancing the boring, sampling of materials is generally performed. Samples fall into two broad categories: disturbed samples and undisturbed samples. For an existing dam, the analyses must be directed towards determining the stability of the dam as it stands. Thus, for existing dams, undisturbed samples should be obtained for testing since these samples are more representative of the materials in place. Testing these undisturbed samples normally provides the best available data and hence, the most accurate means for determination of strength parameters and structural stability. Undisturbed samples are generally obtained during boring operations using Shelby tube or other thin-walled samplers.

Disturbed samples are most accurately used to determine general engineering properties of embankment soils and shear strength parameters for new construction. Disturbed materials may be remolded to a specified density and samples extracted for laboratory tests for the remolded soil. The test results obtained using remolded samples may or may not accurately depict the shear strength of an existing embankment and should not be used for this purpose. However, tests on remolded samples are commonly used and do accurately depict the shear strength of similar materials placed in new or remedial construction at or near the density of the remolded specimen. Disturbed samples are usually obtained from the Standard Penetration Test (described below) and from material cuttings generated during the advancing of the borings.

Additional information which may be obtained during the sampling operation is the blow count resulting from the Standard Penetration Test. This test can be performed at intervals of each two and one half feet in the boring and is referenced by the American Society for Testing and Materials (ASTM) in testing designation D 1586-67 (1974). The blow count is the number of blows required to drive a split spoon sampler a depth of 12 inches. The blow counts can be valuable in identifying loose or soft zones in the embankment which may indicate areas of low strength. Blow counts can also serve as an indicator for an estimate of shear strength.

The location of any sample should be properly documented, that is, record the particular boring and depth from which the sample was taken. The boring logs should reflect all samples taken. Samples selected for testing must be cross referenced to the specific location in the boring information.

Other field tests which can be performed in conjunction with the area of exploration include:

1. Pressure Tests: The pumping of water into a boring at selected intervals to evaluate the leakage or water tightness of the zones; such tests are normally limited to rock zones in the foundation.

2. Dye Tests: The introduction of dye into a boring to aid in determining sources and zones of seepage.

3. Installation of Observation Wells or Piezometers: Cased borings and instrumentation used to determine the elevation of the phreatic surface or water pressure at selected locations. The determination of the phreatic surface in the field exploration should be made at the time of boring and be monitored at regular intervals for changes with respect to time, pool level, season of the year, drainage improvements, etc.

4. Cased Borings: Borings are sometimes cased to provide observation wells and provide a means for checking slope movements by use of instruments generically called inclinometers.

5. Weirs: Weirs can be installed to provide a means for measuring seepage quantities. These weirs may be installed at selected points of interest or at positions which will collect essentially all of the seepage for measurement.

TESTING

The purpose of laboratory testing is to classify embankment and foundation soils and rock, and to determine their engineering characteristics. There are many indices and parameters presently in use and various methods are employed for obtaining engineering data. Certain of these indices, parameters, and tests have gained a wider acceptance and application than others. Those which are most applicable to the testing process on existing earth dams are noted below:

1. Particle Size Analysis: This analysis determines the percentages of soil particles which are of various sizes. This test basically breaks the soil into percentages of gravel, sand, silt and clay. These percentages are necessary for soil classification and for the design of systems to control and filter seepage.

2. Atterberg Limits: These indices define moisture contents at which the soil can have different states, thereby loosely establishing the nature of the soil within a range of moisture content. One indicator obtained from these tests is the Plasticity Index which defines the range of moisture contents over which the soil is plastic. The magnitude of this range can be an indication of the susceptibility of the soil to piping (internal erosion).

3. Soil Classification: There are several different systems for assigning the soil to a generalized classification group. A significant amount of research and information has been accumlated on the basis of soil classification. Similar soils, in terms of classification, generally have similar engineering properties. The soil classification is commonly used to obtain preliminary values of engineering characteristics and to provide a degree of reliability for values determined in testing. The Unified Soil Classification System is the system most employed by the Division. This classification system is based primarily on the results of the particle size analysis and the Atterberg limits noted previously.

4. Moisture Content: This test gives the percentage, by weight, of water in any selected sample. When used in conjunction with other tests, such as the Atterberg Limits, moisture content is useful as an indicator of soil behavior, that is, its potential to function as intended.

5. Specific Gravity: Specity Gravity is necessary in many laboratory tests and is used to relate the weight of a soil to its volume.

6. Proctor Density: In these tests a fixed amount of compactive effort is used to compact a soil. In common usage, the tests normally performed are the Standard Proctor test and the Modified Proctor test. The basic difference in proctor tests is the compactive effort. Different tests use differing amounts of energy to compact the soil samples. The soil at a given density and moisture content can be tested for strength parameters and used as an index test for existing embankment materials. There is considerable information available which relates shear strength parameters to density and moisture content.

7. Natural Moisture Content and Unit Weight:- These determinations can and should be made from existing embankment samples and correlated to the other laboratory tests. Unit weights and moisture contents are basic to nearly all geotechnical analyses and essential to such matters as slope stability. This data can be used in comparison with standard tests values, such as those noted in Table 1, to obtain preliminary values for engineering properties of interest.

SHEAR STRENGTH DETERMINATION

Various tests are used to determine the shear strength of soils. These include unconfined compression tests, direct shear tests, and triaxial shear tests. Each type of test yields information which is of value in evaluating the stability of an embankment. The different tests are performed under different loading conditions simulating various conditions of field loading and are not directly comparable. There is considerable discussion about when various test results should be used.

The object of these guidelines is not to develope an in depth comparison of the different types of tests. It is sufficient to state that different testing methods all have merit. We will attempt to set forth a rationale and statement of the testing deemed adequate to assess the structural stability of an existing dam. The Division of Water believes that when properly performed, the triaxial shear test yields results which permit more confidence to be placed in subsequent analyses.

There are three conditions under which the triaxial test is generally performed. These are the unconsolidated-undrained (UU), consolidated-undrained (CU), and the consolidated-drained (CD) tests. The consolidation and drainage terms refer to the preparation of the sample prior to testing and the drainage condition during testing. Due to the time involved in performing drained tests, the undrained tests are most commonly performed. For the purposes of evaluating the shear strength parameters of existing dams the consolidated-undrained (CU) test is normally performed.

When a consolidated-undrained triaxial test is performed, not only can the applied pressures be measured, but monitors can be used to measure the magnitude of the pressure which is experienced by the water which is located in the soil sample, that is the water in the voids between the soil particles (pore water). Since this pore water carries some of the applied pressure it is obvious that the soil particles also carry part of the applied pressure. Therefore, measurement of the pore water pressure permits the data to be reduced to the pressure which is borne only by the soil particles.

If the shear strength parameters are obtained from the reduced data obtained from the measurement of the pore water pressure, they are referred to as effective stress parameters. If the unreduced data is used, the strength parameters are referred to as total stress parameters. Both the effective and the total stress parameters are used in the analyses necessary to evaluate the stability of a dam when subjected to different loading conditions. In general, the effective stress parameters are of the most benefit in analyzing existing embankments.

Table 1 has been reproduced from the publication of the Department of Defense entitled Design Manual: Soil Mechanics, Foundations, and Earth Structures (NAVFAC DM-7) as a reference for average engineering properties of soils compacted to 100 percent of Standard Proctor. This information provides a means for both making preliminary estimates and checking values obtained in actual testing.

When a geotechnical report is submitted to the division as part of an overall investigation or in conjunction with plans for the repair or reconstruction of a dam, the laboratory data sheets should be included.

TABLE 1

Typical Properties of Compacted Materials

Group symbol	Soil type	Range of maximum dry unit weight, pcf	Range of optimum moisture, percent	Typical value of compression: At 1.4 tsf (20 psi)	Typical value of compression: At 3.6 tsf (50 psi)	Typical strength characteristics: Cohesion (as compacted) psf	Typical strength characteristics: Cohesion (saturated) psf	Typical strength characteristics: ϕ (Effective stress envelope) degrees	Typical strength characteristics: Tan ϕ	Typical coefficient of permeability ft/min.	Range of CBR values	Range of subgrade modulus k lb/cu in.
				percent of original height								
GW	Well graded clean gravels, gravel-sand mixtures.	125 - 135	11 - 8	0.3	0.6	0	0	>38	>0.79	5×10^{-2}	40 - 80	300 - 500
GP	Poorly graded clean gravels, gravel-sand mix.	115 - 125	14 - 11	0.4	0.9	0	0	>37	>0.74	10^{-1}	30 - 60	250 - 400
GM	Silty gravels, poorly graded gravel-sand-silt.	120 - 135	12 - 8	0.5	1.1	....	....	>34	>0.67	$>10^{-6}$	20 - 60	100 - 400
GC	Clayey gravels, poorly graded gravel-sand-clay.	115 - 130	14 - 9	0.7	1.6	....	....	>31	>0.60	$>10^{-7}$	20 - 40	100 - 300
SW	Well graded clean sands, gravelly sands.	110 - 130	16 - 9	0.6	1.2	0	0	38	0.79	$>10^{-3}$	20 - 40	200 - 300
SP	Poorly graded clean sands, sand-gravel mix.	100 - 120	21 - 12	0.8	1.4	0	0	37	0.74	$>10^{-3}$	10 - 40	200 - 300
SM	Silty sands, poorly graded sand-silt mix.	110 - 125	16 - 11	0.8	1.6	1050	420	34	0.67	5×10^{-5}	10 - 40	100 - 300
SM-SC	Sand-silt clay mix with slightly plastic fines.	110 - 130	15 - 11	0.8	1.4	1050	300	33	0.66	2×10^{-6}	....	
SC	Clayey sands, poorly graded sand-clay mix.	105 - 125	19 - 11	1.1	2.2	1550	230	31	0.60	5×10^{-7}	5 - 20	100 - 300
ML	Inorganic silts and clayey silts .	95 - 120	24 - 12	0.9	1.7	1400	190	32	0.62	10^{-5}	15 or less	100 - 200
ML-CL	Mixture of inorganic silt and clay	100 - 120	22 - 12	1.0	2.2	1350	460	32	0.62	5×10^{-7}	....	
CL	Inorganic clays of low to med. plasticity.	95 - 120	24 - 12	1.3	2.5	1800	270	28	0.54	10^{-7}	15 or less	50 - 200
OL	Organic silts and silt-clays, low plasticity.	80 - 100	33 - 21	....	....	....	....	....	.....	....	5 or less	50 - 100
MH	Inorganic clayey silts, elastic silts.	70 - 95	40 - 24	2.0	3.8	1500	420	25	0.47	5×10^{-7}	10 or less	50 - 100
CH	Inorganic clays of high plasticity	75 - 105	36 - 19	2.6	3.9	2150	230	19	0.35	10^{-7}	15 or less	50 - 150
OH	Organic clays and silty clays ...	65 - 100	45 - 21	....	....	....	....	....	.....	....	5 or less	25 - 100

Notes:

1. All properties are for condition of "standard Proctor" maximum density, except values of k and CBR which are for "modified Proctor" maximum density.
2. Typical strength characteristics are for effective strength envelopes and are obtained from USBR data.
3. Compression values are for vertical loading with complete lateral confinement.
4. (>) indicates that typical property is greater than the value shown. (....) indicates insufficient data available for an estimate.

ANALYSIS

Various methods have been developed to evaluate the likelihood of a slope failure occurring in an embankment. In general, these methods assume the shape of a failure surface through an embankment. After the failure surface has been assumed, there will be forces (gravity, seepage) tending to cause failure and other forces (cohesion, friction) which resist failure. In simplified terms, the ratio of the resisting forces to those tending to cause failure is the factor of safety. Assumptions are required in each method of analysis to account for unknown forces. The engineer must be aware of any assumptions and satisfy himself that any particular method is applicable.

One of the most widely used methods of analysis is the Simplified Bishop method. This method, as others, makes simplifying assumptions about some of the forces that must be accounted for in the stability analysis. It is also based on the assumption that the failure surface is circular. While the simplifying assumptions employed in this method may not entirely satisfy all the requirements for a rigorous analysis, the results are usually conservative and extensive application by many engineers has permitted a widely accepted level of confidence in this method.

In some instances, a circular failure surface may not be appropriate, as in some zoned embankments. Analyses utilizing a plane failure surface rather than a circular failure have been developed and are commonly referred to as wedge analyses. One example of this type of analysis can be found in NAVFAC DM-7.

For existing dams, the stability analyses should address the stability under at least two loading conditions. These are the long-term steady seepage condition and the rapid drawdown condition. On new dam construction, an additional loading condition reflecting the end-of-construction or of certain phases of construction is sometimes necessary. In some areas of Kentucky, most notably western sections, earthquake loading must be considered. An earthquake analysis is normally associated with the long-term steady seepage condition.

The rapid drawdown condition occurs when the water level in the reservoir is lowered in a rapid manner, such that the drainage of pore water from within the embankment does not occur to a major extent. This results in a saturated zone of embankment on which water forces acting as support have been removed. Since the pore water would eventually drain, this is termed a transient condition and a lesser factor of safety is acceptable. An analysis for the rapid drawdown condition utilizes effective stress parameters since the effect of pore water must be taken into account during the analysis.

The long-term steady seepage condition represents the condition under which a dam will exist most of the time. The dam has been in place long enough for all excess pore water pressures in the embankment and foundation to dissipate and for the phreatic surface, or level of seepage through the dam, to become fully developed. It is noted that seepage occurs on all earthfill dams. Seepage must, however, be controlled and filtered to assure that it is not detrimental to the integrity of the dam. Since water has no resistance to shearing forces, the contribution to shearing resistance must come solely from the soil s cohesion and interlocking properties (intergranular friction). Thus, the long term steady seepage condition is analysed using the effective stress shear strength parameters which account for the effects of pore water pressure within the embankment.

As noted previously, there is a significant area where earthquake loadings must be considered. The area of greatest seismic risk is in western Kentucky. The seismic loading on a dam is most commonly applied in the form of a factor which increases the existing load from a non-seismic condition. This additional loading is approximated in some computer programs by the application of a seismic coefficient. One such program which utililizes this type of analysis is the REAME program which is in wide usage in Kentucky.

The result of any type of stability analysis, circular or wedge, with any method, will be the factor of safety against slope failure for the condition being analyzed. Because of the uncertainty in exploration, and noting the fact that the exploration can not cover all areas, the safety factor must be large enough to address many uncertainties. Table 2 gives the factors of safety associated with various loading conditions and the reservoir at the normal pool level which are generally accepted by the engineering profession.

TABLE 2

FACTORS OF SAFETY

Factors of Safety and Recommended Analysis for Selected Conditions

Loading Condition	Factor of Safety	Basis for Shear Strength
Rapid Drawdown	1.2	Effective Stress Analysis
Long-Term Steady Seepage	1.5	Effective Stress Analysis
Earthquake Loading	1.0	Effective Stress Analysis

The factors of safety noted in the table are considered to be the minimum acceptable values. That is, the degree of risk to lives and property must not be increased above this value. Any construction, reconstruction, or modification to dams must result in the establishment of the minimum acceptable factor of safety for the appropriate loading condition.

CONCLUSION

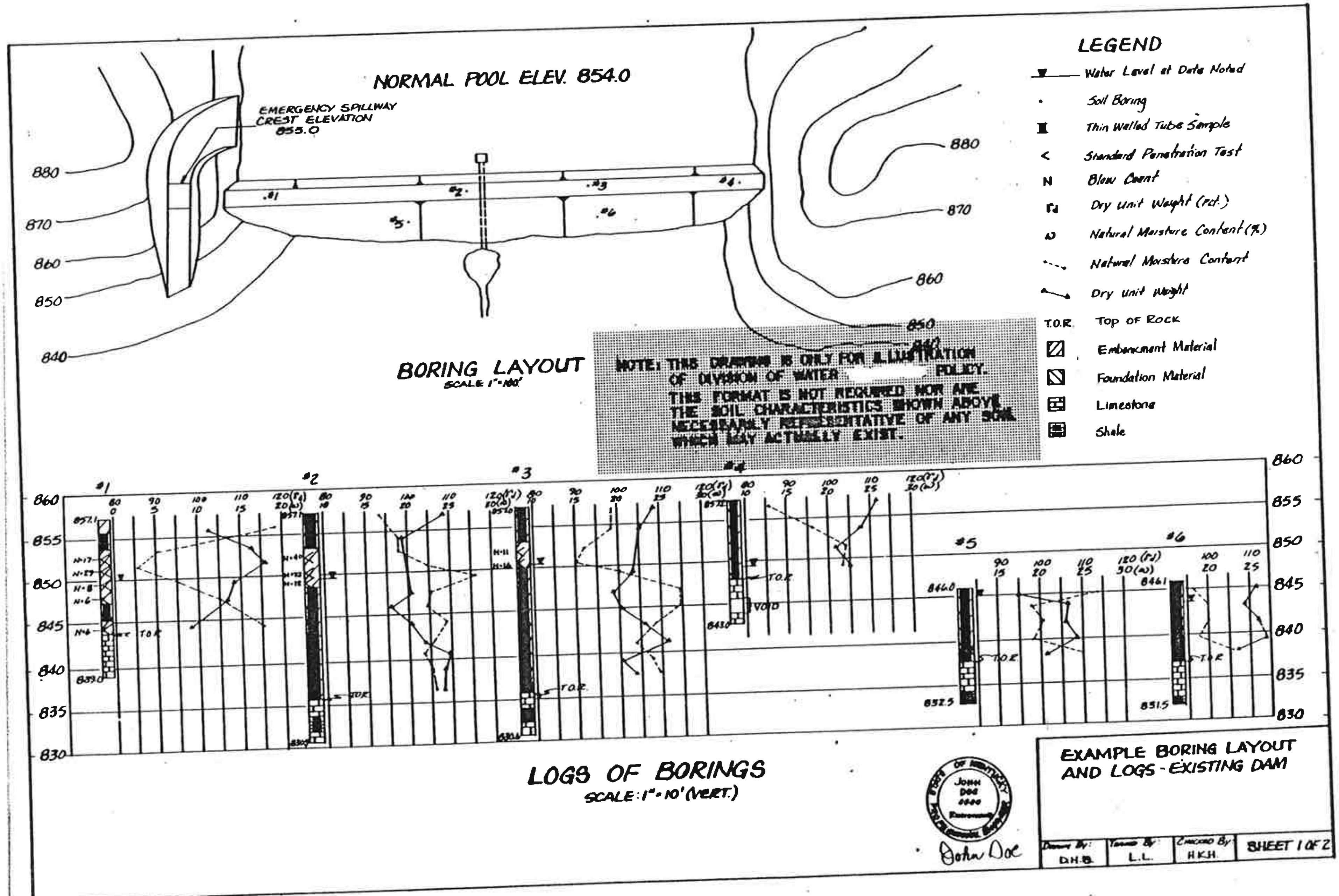
As noted earlier, the purpose of these guidelines is to present a basic discussion on the types of information required to adequately assess the structural stability of an existing earthfill dam. We feel that owners should be aware of the general types of information needed and have some understanding of the nomenclature involved. Engineers should be able to benefit by having a better understanding of the information the division requires to assess the structural stability of a dam.

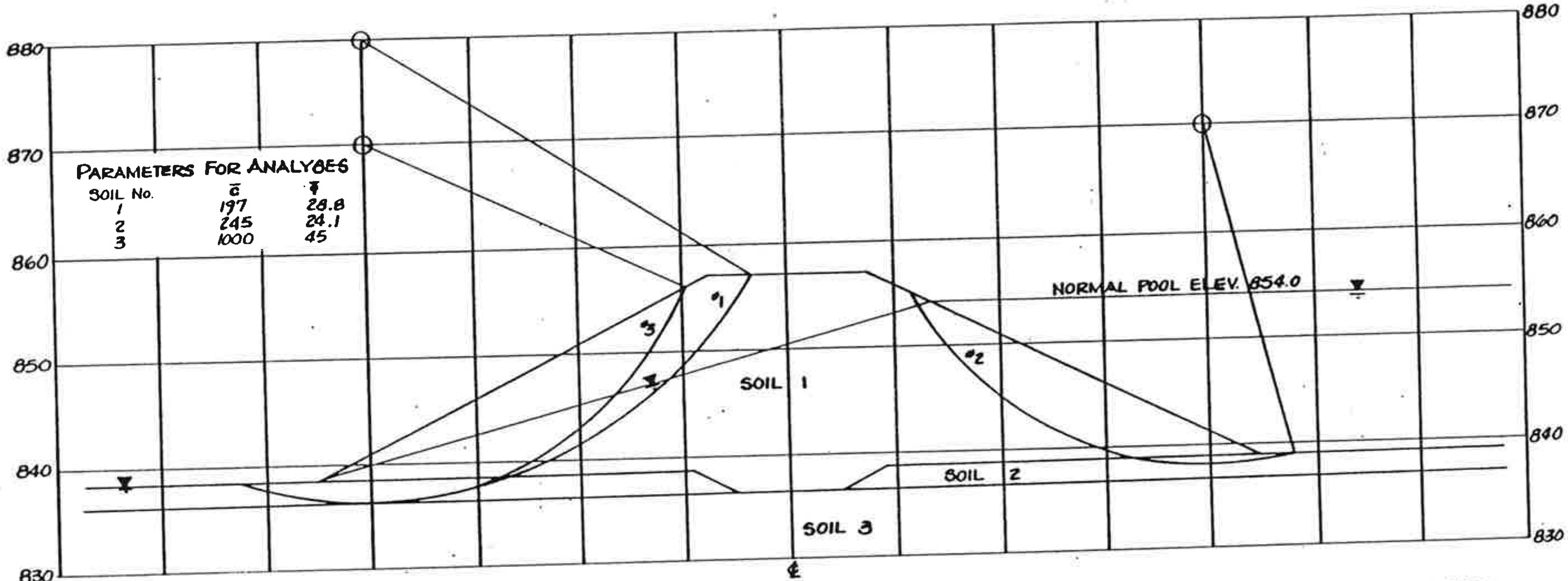
Basic areas which should be addressed in a geotechnical investigation have been set forth in broad terms. Each investigation is, of course, site specific, and it is not likely that any single document can be adequately applied to all dams. The areas mentioned in this document are, in large part, germain and applicable to any investigation on a dam and fulfill the basic purpose of providing guidance and information to the owner and the engineer.

The basic purpose in performing a geotechnical investigation is to determine the structural stability of a dam. Such a determination should be performed in accordance with state-of-the-art techniques. An attainment of minimum factors of safety does not guarantee that failure can not occur, but rather, that steps have been taken in line with reasonable and prudent practice to assure the structural stability of the dam. A dam which does not fulfill minimum safety criteria can not be considered adequate and does not provide the minimum degree of risk considered acceptable. The primary responsibility for the safety of the dam rests with the owner and operator of the dam.

As an appendix, we have prepared a sample set of drawings which contain the basic information set forth in this discussion. The sample set is intended to provide a reasonable example of the results of a geotechnical investigation. While this format is not required, it can be applicable to many geotechnical investigations and it is offered as an example of the type of information required to properly evaluate an existing structure from the standpoint of structural stability.

APPENDIX


NORMAL POOL ELEV. 854.0
EMERGENCY SPILLWAY CREST ELEVATION 855.0
880
870
860
850
840
BORING LAYOUT
SCALE 1"=100'
NOTE: THIS DRAWING IS ONLY FOR ILLUSTRATION OF DIVISION OF WATER POLICY.
THIS FORMAT IS NOT REQUIRED NOR ARE THE SOIL CHARACTERISTICS SHOWN ABOVE NECESSARILY REPRESENTATIVE OF ANY SOIL WHICH MAY ACTUALLY EXIST.
LEGEND
Water Level at Date Noted
Soil Boring
Thin Walled Tube Sample
Standard Penetration Test
N Blow Count
Dry Unit Weight (Pcf.)
Natural Moisture Content (%)
Natural Moisture Content
Dry Unit Weight
T.O.R. Top of Rock
Embankment Material
Foundation Material
Limestone
Shale
LOGS OF BORINGS
SCALE: 1"=10' (VERT.)
VOID
EXAMPLE BORING LAYOUT AND LOGS - EXISTING DAM
Drawn By: D.H.B.
Traced By: L.L.
Checked By: H.K.H.
SHEET 1 OF 2
John Doe



EMBANKMENT STABILITY SECTION
SCALE: 1"=10'

NOTE: SECTION DEVELOPED FROM SUBSURFACE EXPLORATION AND CONSTRUCTION DRAWINGS.

SOIL TEST RESULTS

SAMPLE	#1	#2
BORING	#2	#6
DEPTH	10.5'-12.5'	7.0'-9.0'
MATERIAL	EMBANKMENT	FOUNDATION
COMPOSITION: GRAVEL	0	0
SAND	13	23
SILT	40	38
CLAY	47	39
LIQUID LIMIT	33	32
PLASTIC LIMIT	16	18
PLASTICITY INDEX	17	14
SPECIFIC GRAVITY	2.71	2.66
UNIFIED CLASSIFICATION	CL	CL
MAXIMUM DRY DENSITY	108.6	106.1
OPTIMUM MOISTURE	17.6	18.1

TRIAXIAL TEST RESULTS

SAMPLE	EFFECTIVE STRESS SHEAR STRENGTH PARAMETERS		UNIT WEIGHT (P.C.F.)
	$\bar{c}$ PCF	$\bar{\phi}$ °	
#1	197	28.8	125
#2	245	24.1	120

SUMMARY OF STABILITY ANALYSES

CIRCLE	CONDITION	F.S.
1	STEADY STATE-NORM. POOL	1.72
2	RAPID DRAWDOWN	1.35
3	DYNAMIC-NORM. POOL	1.54

STATE OF KENTUCKY JOHN DOE 0000 REGISTERED PROFESSIONAL ENGINEER

John Doe

EXAMPLE TESTING AND ANALYSES RESULTS

DRAWN BY:	TRACED BY:	CHECKED BY:	
D.H.B.	L.L.	H.K.H.	SHEET 2 OF 2